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QUARTERLY PROGRESS REPORT

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Bellcomm

QUARTERLY PROGRESS REPORT

January February March

1970

I. M. Ross
President

Bellcomm
955 L'Enfant Plaza North, S. W. Washington, D. C. 20024

Report No. 70-101-2
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QUARTERLY PROGRESS REPORT

ABSTRACT

The activities of Bellcomm during the quarter ending March 31, 1970 are summarized. Reference is made to reports and memoranda issued during this period covering particular technical studies.

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MISSION PLANNING

Mission Assignments

A new version of the Apollo Flight Mission Assignments document was prepared; however, issuance was postponed because of the cancellation of the Apollo 20 flight and the reprogramming necessitated by that decision. A new Apollo 13 Appendix of the Apollo Flight Mission Assignments document was approved in January and subsequently issued by NASA as a revision to the then current issue. The new appendix contained science rationale for both the prime site, Fra Mauro, and the backup site, Flamsteed. Also, the primary objectives were reworded and detailed objectives updated.

A second new issue of the Apollo Flight Mission Assignments document was prepared in draft form. The draft reflects the results of the March meeting of the Apollo Site Selection Board and identifies the site science rationale and the primary objectives for the remaining Apollo missions.

Technical activities in support of the Apollo 13 Mission included participation in reviews of the flight plan and mission rules. A recommendation was made and accepted that there be a specific mission rules section covering lunar surface EVA.

Vehicle Performance

Preparation and delivery of the Quarterly Weight and Performance Report, as well as presentation of weight and performance status at Apollo Program Office Reviews, continued. A recommendation to discontinue publication of the monthly Weight and Performance Summary was approved by the Apollo Program Director. The Quarterly Weight and Performance Summary will continue to be published.

Analytical work relating J-mission spacecraft weight and performance capabilities and requirements for specific launch dates and landing sites continued. Results of this effort were presented to the Apollo Program Director on January 14. A set of control weights for both the spacecraft and the launch vehicle were recommended, approved by NASA, and subsequently transmitted to the Centers.

A proposal to calibrate the LM descent propellant tanks and the Propellant Quantity Gauging System (PQGS) in the tanks was evaluated.[1] It was shown

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(1) Calibration of the Descent Propulsion System Propellant Tanks and Propellant Quantity Gauging System, Memorandum for File, K. P. Klaasen, March 5, 1970.

that a pre-mission calibration of the PQGS in the region from 10% propellant remaining to depletion could result in a possible increase of about 90 pounds in LM payload capability on future missions. This possible improvement on future missions would be obtained through more accurate knowledge of past mission performance as provided by a calibrated PQGS.

Mission Analysis

The major emphasis of work in this area during the quarter was on mission planning for the J-mission series. In order to establish the relationship between the number of mission opportunities and the vehicle weights, performance scans were completed for missions to Marius Hills, Descartes, Copernicus, Apennine-Hadley, Davy, Rima Bode and Hyginus for the period 1971 through 1974. The corresponding mission-specific launch vehicle energy requirements were also determined.

On February 24, the Apollo mission performance status was reviewed with the Apollo Program Director as appropriate to provide background for the March Apollo Site Selection Board Meeting.

A method of determining lunar accessibility contours that allows the establishment of accessible areas subject to a lunar landing lighting constraint has been developed.[2] This method has been used to determine the location of the areas on the moon accessible for the first J-mission should it have to be flown in October or November of 1971.

In conjunction with efforts to determine feasible, multi-impulse trajectories for a landing at the crater Tycho, a parametric analysis of a three-impulse transfer between a circular lunar orbit and a hyperbolic orbit has been performed.[3] From the data presented it is possible to determine when a three-impulse maneuver will result in a ΔV savings and the magnitude of the savings or penalty. It is shown that while ΔV savings can be as high as 4600 fps, typical savings are around 2000 fps for a landing site such as Tycho.

Photography of the Apennine-Hadley site was planned as part of a mission to Littrow. A parametric study of the orbital maneuvers required to accomplish this photography has been completed.[4]

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(2) Determination of Apollo Lunar Surface Accessibility Subject to DPS Abort and Lighting Constraints, TM-70-2013-2, R. A. Bass, R. J. Stern, March 31, 1970.

(3) Parametric Analysis of Three-Impulse Transfer Between Hyperbolic Lunar Orbit and a Circular Lunar Parking Orbit, TM-70-2013-1, M. R. Kerr, March 18, 1970.

(4) Plane Change ΔV Requirements for "Bootstrap" Photography of Hadley-Apennine During a Mission to Littrow, Memorandum for File, R. A. Bass, C. L. McGarry, January 27, 1970.

The 210-foot antenna coverage data for the Apollo 13 mission was extended to include a May launch.(5)

Guidance and Navigation

One feature of the Delta Guidance scheme that had been considered for LM descent was a series of "throttle-downs" during the braking phase, if the engine and fuel valves were performing well. Up to 90 fps could be saved this way. A study was conducted to insure that these savings existed if engine efficiency was reduced markedly during the "throttle-downs".(6) At present, the program is not planning to use this technique. Instead, the descent will be retargeted, planning on good engine and fuel valve performance, to achieve approximately a 60 fps saving. The retargeted trajectory is still under study.

The terrain near the Apollo 13 landing site is uphill, then downhill, and noticeably affects the trajectory through the landing radar. A study showed the crew could be misled by as much as 3500 feet as to where the computer would land the LM. The data were made available to the crew, so that they could purposely bias the landing point designator.(7)

A method has been developed for correcting the LM Alignment Optical Telescope (AOT) fields of view for landed LM attitude other than nominal.(8) The method is implemented by means of charts which allow the center of the AOT detent fields of view to be located against the star background for any attitude deviations. In most cases, the angular orientation of the detent reticle can also be found.

As with earlier missions, star locations relative to the LM telescope while on the moon were diagrammed for Apollo 13.(9) The reports have been used by both MSC and the crews.

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(5) 210-Foot Antenna Coverage for the Apollo 13 Mission in May 1970, Memorandum for File, D. R. Anselmo, M. K. Burchette, March 13, 1970.

(6) The Effect on Vehicle Performance of Thrust and Isp Variations Due to Delta Guidance Thrust Modulations, Memorandum for File, J. A. Sorenson, March 5, 1970.

(7) Lurain Effects on the LM Trajectory and Landing Point Designator Accuracy for Apollo 13, Memorandum for File, G. M. Cauwels, F. LaPiana, March 9, 1970.

(8) AOT Star Chart Compensation for LM Landing Attitude Deviations, Memorandum for File, K. M. Carlson, March 13, 1970.

(9) Stars and Planets Visible in the LM AOT During the Lunar Stay Time of the Apollo 13 Mission, Memorandum for File, T. L. Yang, March 26, 1970.

To assist in future attempts to track the spent S-IVB stage after its slingshot maneuver, the capability to use optical tracking data has been added to Bellcomm's Orbit Determination Program. Some Apollo 12 S-IVB optical tracking data are available, but comparison to S-band tracking data are not conclusive.[10]

The Time-Varying Orbital Elements approach to orbital navigation as developed by Bellcomm was presented at a convention of the Institute of Navigation in February. The method was applied successfully to Apollo 12 data.[11] A study has now begun to see if it offers a useful new way to deduce gravity potential model coefficients.

Gravity potential model coefficients may be transformed from one coordinate system to another by methods outlined in a Bellcomm report, which has been submitted for publication by the AIAA.[12]

A study showed that VHF ranging and Crewman Optical Alignment Sight (COAS) angle measurements could substitute for the rendezvous radar measurements, thereby saving up to 90 pounds.[13]

The two major ways of targeting translunar midcourse corrections are called XYZT (pass through a near nominal place near the moon at a near nominal time) and "Free Return Best Adaptive Path" (for free return trajectories). A study shows them to be virtually identical with current TLI injection accuracy.[14]

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(10) Addition of Right Ascension and Declination Observables into BCMTAP, Memorandum for File, J. T. Findlay, March 11, 1970.

(11) Lunar Orbit Determination for Apollo 12 Using POLAR, TM-70-2014-5, A. J. Ferrari, M. V. Bullock, March 31, 1970.

(12) Transformation of a Potential Function Under Coordinate Rotations, TR-70-310-1, S. L. Levie, February 18, 1970.

(13) Rendezvous with VHF Ranging and COAS, Memorandum for File, W. O. Covington, March 26, 1970.

(14) XYZT Targeting of the First Translunar Midcourse Correction, TM-70-2014-4, S. L. Levie, Jr., February 11, 1970.

APOLLO/SATURN SYSTEMS ENGINEERING
PERFORMANCE AND DESIGN REQUIREMENTS

Apollo Program Specification

Specification Change Notices for Revision C of the Apollo Program Specification, covering the J-series missions, were prepared and submitted to the Level 1 Change Control Board and approved on March 30, 1970.

Communication Systems

Design alternatives for minimizing the power requirements and size of the Lunar Communications Relay Unit (LCRU) were studied. It was found that the LCRU transmitter power necessary to meet existing NASA standards for television reception through MSFN receiving stations with 85' antenna could be reduced from 10 watts to 5 watts by either increasing the size of the LCRU antenna or decreasing the input bandwidth of the FM demodulators in the MSFN stations.(15) A brief study was made of a proposal for using a hinged reflective flap on the LCRU case for passive thermal control.(16)

The earth elevation and azimuth as viewed from the lunar surface is required in order to assess orientation requirements on the lunar roving vehicle communications antenna during a lunar mission. The required azimuth and elevation data was determined for eight lunar landing sites for the period from July 1, 1971 through December 31, 1975.(17) It was further shown that systems losses of less than 3 db are maintained without repointing of the antenna within a ± 75° azimuth sector at sites where the earth elevation angle is high, such as Descartes, and the azimuth sector decreases to ± 35° at sites, such as Tycho, where the earth elevation angle is low. A graphic summary of the study results was provided to the Lunar Surface Reference Mission Plan Group at MSC for use in analysis of requirements for constraining the traverse direction or repointing the antenna to maintain continuity of communication with earth.

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(15) Alternative Designs for the Television Transmission System of the Lunar Communications Relay Unit (LCRU) and their Communication Link Performance, Memorandum for File, R. L. Selden, February 4, 1970.

(16) Thermal Performance of the LCRU with Adjustable Flap, Memorandum for File, A. S. Haron, February 17, 1970.

(17) Lunar Communications Relay Unit (LCRU) Pointing Angles for Earth Communications from Eight Lunar Science Sites, Memorandum for File, M. K. Burchette, March 9, 1970.

A method was demonstrated for quickly identifying areas of a lunar site where a line-of-sight path is available between a radiating antenna and an extravehicular astronaut. A point light source is located at the scaled height of the antenna or astronaut on a relief topographical map with a 1:1 vertical/horizontal scale, and line-of-sight areas are delineated for real-time interpretation or photography.[18]

Candidate functional requirements for television in Apollo lunar surface operations were identified to provide a basis for deriving a ranked set of requirements and selecting an appropriate system for Apollo use.[19] It has been proposed that television cameras be remotely controlled from the Mission Control Center on later Apollo lunar surface operations. A study of time delay in such a system showed that the interval between command initiation and observed response would range from three to three and one-half seconds. Premission training with simulated delays of this magnitude was recommended.[20]

Lunar Surface Operational Capabilities

Operational constraints were defined for lunar surface traverses conforming to previously established J-mission requirements.[21] Nominal and real-time alternate timelines were developed for a 54-hour lunar surface staytime with three 6-hour EVA periods. Overhead activities and time remaining for travel and science were identified. Metabolic costs for overhead activities were calculated and nomographs were provided for estimating available science time for various total traverse distances.

A set of traverses for use in evaluating the capability of the Lunar Roving Vehicle (LRV) was developed jointly with representatives of the Marshall Space Flight Center and the United States Geological Survey. These were constructed by using selected traverse segments from available detailed Fra Mauro planning, and assembling them in a manner to reflect terrain conditions at three candidate J-mission sites — Marius Hills, Copernicus Peaks and Hadley-Apennines.[22]

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(18) This was subsequently reported in Use of Shadow Map Techniques to Estimate LM/EVA Line-of-Sight, Memorandum for File, H. Kraus, I. I. Rosenblum, April 6, 1970.

(19) Candidate Functions for Apollo Lunar Surface Television Systems, Memorandum for File, J. C. Slaybaugh, February 6, 1970.

(20) Time Lag Associated with Remote Control of Apollo Lunar Surface TV Camera, Memorandum for File, J. E. Johnson, March 30, 1970.

(21) Operational Constraints for J Mission Traverse Planning, Memorandum for File, P. Benjamin, January 7, 1970.

(22) LRV Design Evaluation Traverses, Memorandum for File, P. Benjamin, J. W. Head, January 13, 1970.

A modular timeline approach was developed for estimating the overhead activities associated with operation of the Lunar Roving Vehicle, Lunar Communications Relay Unit, and television during traverses.(23) It was found that these activities consume a significant fraction of the available EVA time.

Lunar Roving Vehicle Studies

Candidate system requirements and guidelines for the LRV were prepared. These were used in various design review meetings, revised to reflect Center comments, and eventually formed the basis for requirements issued by the Apollo Program Office. Appropriate portions of these requirements were subsequently incorporated in Revision C of the Apollo Program Specification.(24, 25) The LRV Contract End Item Specification was reviewed, and technical comments were formally submitted for use in the Preliminary Design Review.

Functional requirements for the LRV navigation system were developed using crew safety and mission success criteria. Against these requirements, it was noted that a navigation system with polar coordinate displays, as presently planned, did not appear optimum and a rectangular coordinate display with compatible update capability would offer significant advantages.(26) A simplified computer model of the LRV navigation system has been developed for use in analysis of the system requirements and capabilities.

Equations of motion were developed for representation of a four-wheeled independent suspension vehicle traveling over selected lunar terrain models. Using these, a computer program was developed to evaluate the stability characteristics of the LRV under various configuration and terrain conditions.(27)

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(23) Modular Timeline Elements for Lunar Roving Vehicle Traverse Station Stops, Memorandum for File, J. C. Slaybaugh, March 24, 1970.

(24) Candidate Requirements for Top Level LRV Specifications, Working Note to B. Milwitzky, NASA/MAL, from R. D. Raymond, January 2, 1970.

(25) LRV Requirements for Level I Control, Negotiated at MSFC January 15, 1970, Memorandum for File, R. D. Raymond, January 20, 1970.

(26) Science Requirements for an LRV Navigation System, Memorandum for File, P. Benjamin, January 23, 1970.

(27) Equations of Motion of the Lunar Roving Vehicle, TM-70-2031-1, S. Kaufman, March 31, 1970.

Life Support System Studies

An analysis was made of dehydration effects on astronaut performance during lunar surface extravehicular activities.(28) It was concluded that each crewman would require approximately eight ounces of water for each hour that surface activity is extended beyond four hours.

Requirements for primary and secondary life support systems were reviewed in the light of currently proposed lunar surface and orbital extravehicular activities of the J missions.(29) It was confirmed that the increased metabolic capability of the proposed -7 Primary Life Support System (PLSS) was needed. It was found that the requirements for a Secondary Life Support System (SLSS) could be met, though with decreased margin, by an alternate proposal, the Buddy Secondary Life Support System (B/SLSS) which involved partial sharing of one -7 PLSS by both astronauts in an emergency. Compatibility of the B/SLSS with orbital EVA and LRV operation was found to need additional study.

An analysis was made to determine the limits on traverse envelopes which result from two options for battery capability of the -7 PLSS.(30) It was shown that the larger battery permitted more efficient utilization of the metabolic capacity of the -7 PLSS to increase surface exploration capability.

Orbital Science Requirements

A preliminary timeline was formulated for J-mission orbital science activity. Using the timeline, a power consumption analysis was performed and a power profile constructed. The electrical energy requirements for equipment unique to orbital science data acquisition were found to be significantly higher that previously assumed.(31)

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(28) Preliminary Evaluation of Water Loss Effects During EVA, Memorandum for File, T. A. Bottomley, January 12, 1970.

(29) Buddy System and -7 PLSS Presentation, Memorandum for File, P. Benjamin, T. A. Bottomley, P. F. Sennewald, February 18, 1970.

(30) Implications of Revised EVA Capabilities on Traverse Envelopes, Memorandum for File, P. Benjamin, J. W. Head, February 26, 1970.

(31) Lunar Orbital Science Experiments Sample Timeline and Preliminary Power Consumption Analysis for the Typical J-Mission, Memorandum for File, G. J. McPherson, Jr., March 26, 1970.

A review was made of a set of materials experiments proposed for performance on the transearth coast phase of Apollo missions. No unique advantages from performing them on Apollo were identified and criteria for undertaking such experiments on Apollo were proposed. It was recommended that these particular experiments be considered for inclusion in the Skylab Program.

Pressure Vessel Safety Factors

The generalized model specification published in the last quarter is being revised for possible issuance at Headquarters level for implementation by the Kennedy Space Center. The purpose is to provide the Centers with a unified basis for treatment of space vehicle pressure vessel safety factors.

Launch Systems

Launch strategy was considered for future missions which are targeted to specific landing sites. Adding launch windows to the first monthly opportunity and/or providing two windows 48 hours apart in the second month were suggested as approaches to increase the probability of a launch.[32]

Space Vehicle Systems

Study of LM descent propellant depletion reserves was continued. It was suggested that operation of the descent engine might be extended beyond current propellent depletion limits on the basis of engine test data which show that helium ingestion has little effect as long as both fuel and oxidizer are available to the engine. A study of the effects of errors in propellant quantity gauging showed the largest potential performance loss to result from imbalances in fuel and oxidizer in initial loading.

Previous studies of spacecraft consumables usages and prediction accuracies were extended to include data from the Apollo 12 mission. Results were similar to previous missions in that prediction accuracy was highest for the larger systems, all significant disparities were attributable to identifiable causes, and the SM RCS continued to be the least predictable system.[33] LM consumable usage rates on the Apollo 11 and 12 missions were analyzed. It was found that there was margin in the LM lunar surface staytime on these missions of 11 and 17.5 hours respectively before depletion of any consumable occurred. In both cases battery capacity was the limiting factor.

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(32) Lunar Exploration Mission Launch-Ability Ratings, Memorandum for File, C. H. Eley, III, February 20,1970.

(33) Precision of Apollo 12 Consumables Estimates, Memorandum for File, S. S. Fineblum, March 20, 1970.

Study of the S-II POGO phenomena continued. Stability analyses using improved structural models compare favorably with flight results in response frequency and occurrence time, but the POGO onset features are not reproduced.[34] A time domain simulation confirms the stabilizing effect of an S-II LOX line accumulator. Mathematical modeling of the MSFC S-II LOX line test setup produces results that get progressively closer to the test data as features are added to describe the pulser characteristics. Contour spectrograms generated from selected Apollo 9 and 12 measurements indicate that the Apollo 9 POGO occurrence was probably associated with a single mode, and provide new insight into the S-IVB LOX line frequency as a function of flight time.

In response to an MSFC request, an analysis was made of their facility for measuring fluid feed line resonant frequencies.[35] It confirmed the validity of certain test results which have been obtained with this facility and recommendations were made to maintain the accuracy of future tests.

A study was performed to determine the implications of a 108,000-pound payload on structural and control dynamics of the Saturn V launch vehicle.[36] Structural safety factors and control system capability were found to be satisfactory.

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(34) A Simplified Analysis of the S-II POGO, Memorandum for File, I. Y. Bar-Itzhack, January 6, 1970.

(35) Analysis of a Test Method for Measuring Resonant Frequencies of Loaded Hydraulic Feed Lines, TM-70-1033-1, G. C. Reis, January 23, 1970.

(36) Impact of J Mission Payload Requirements on L/V Structures and Control Dynamics, Memorandum for File, R. E. Hunter, March 31, 1970.

Site Selection

A presentation on site selection and candidate site assignments was given at the February meeting of the Group for Lunar Exploration Planning. The status of lunar site selection was given at the March Apollo Program Office Review.

Geologic studies of candidate lunar exploration sites continued. Summaries of the scientific rationale for these landing sites were prepared for inclusion in revisions of the Apollo Flight Mission Assignments Document.(37)

Apollo 13

At the request of the Principal Investigator for the Field Geology Experiment, a presentation on the geology of the Apollo 13 landing area was made to a group convened to consider shifting of the Apollo 13 landing ellipse. The meeting resulted in the suggestion of an alternate ellipse to optimize the probabibity of meeting mission science requirements.

At the request of the Mission Scientist, redesignation points were selected such that exposed Fra Mauro material was within traverse distance from each given landing point. A sampling philosophy for the field geology traverse was also developed.

Two other activities were recommended for Apollo 13: recording of observations from lunar orbit and photographing the LM impact point. Both recommendations were implemented in the Apollo 13 Flight Plan.

To support lunar surface mission planning, the available data, including the cartographic products being prepared for Apollo 13, were collected, analyzed, and issued in a memorandum.(38) The products included high and low resolution photography, a topographic map, and a cumulative frequency-of-crater distribution. The expected number of redesignations and the expected total LM descent ΔV were also calculated.

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(37) Scientific Rationale Summaries for Apollo Candidate Lunar Exploration Landing Sites, Memorandum for File, J. W. Head, March 11, 1970.

(38) FRA MAURO - Apollo 13 Prime Landing Site, Memorandum for File, V. Hamza, January 19, 1970.

Nominal pointing angles for observing the Apollo 13 spacecraft and S-IVB were generated for the professional and amateur astronomers who provide optical coverage of the spacecraft and its waste water dumps, as well as act as a backup for tracking the S-IVB to lunar impact.(39)

A study of lunar mascons was completed. The study described a creation mechanism that requires no abnormal density materials nor density inversions.(40) It was proposed that the mascons may have been produced by mantle plugs upwelling into giant impact basins punched through the lunar crust and followed by volcanic filling of the remainder of the crater above the plug. Subsequent analysis of returned lunar samples has contributed additional evidence for the possible existence of such a lunar "Moho".

A study was completed on a possible secondary ejecta mechanism for explaining the seismogram observed when the Apollo 12 LM Ascent Stage impacted the lunar surface.(41) The study concluded that secondary ejecta cannot account for signals arriving earlier than 45 seconds, but could explain the remaining portion of the signal provided that the angular distribution of the secondary ejecta are assumed to peak sharply in the vertical direction. The ejecta model proposed may be more applicable to meteoroids than to the LM, since the secondary ejecta due to meteoroid impact are expected to peak at higher angles.

Lunar Surface Experiments

Analysis of the Apollo 11 Early Apollo Scientific Experiments Package/Dust, Thermal and Radiation Engineering Measurements experiment temperature data continued, with emphasis on refinement of analysis and auxiliary calculations. Preliminary analysis indicated that the lunar surface temperatures determined from the nickel thermometer measurements were significantly hotter than the values calculated from the assumed model at all sun elevations. Calculated thermometer temperatures are now reasonably close to (although systematically cooler than) the measured values. It is concluded that the data can be adequately explained and that the nickel thermometer will yield lunar surface temperature consistent with those previously reported.

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(39) This was subsequently reported in Optical Tracking of Apollo 13, Letter and attachments, J. O. Cappellari, Jr., W. I. McLaughlin, April 2, 1970.

(40) Mascons as Structural Relief on a Lunar Moho, TR-70-340-2, D. U. Wise (University of Massachusetts), M. T. Yates (Bellcomm), January 27, 1970. Also published in "Journal of Geophysical Research," Volume 74, No. 2, January 10, 1970.

(41) A Secondary Ejecta Explanation of a Lunar Seismogram, TM-70-2015-2, G. K. Chang, P. Gunther, D. B. James, March 17, 1970.

The proposed Lunar Surface Experiments Assignments were reviewed for the Apollo Program Office and this input is being used in the final selection process.

The portable magnetometer and the traverse gravimeter were reviewed and recommendations were made to the Program Office. The portable magnetometer has been approved for Apollo 14. The traverse gravimeter is currently being reviewed to determine its compatibility with a rover mission.

Assistance was provided to the Apollo Program Office in drawing up a test program to be used for the comparative evaluation of the Lunar Atmospheric Mass Spectrometers.(42) The comparative test will be carried out at the JPL Molsink Facility during the latter part of the year.

Work continued on the definition and implementation of science reference missions for Marius Hills and Copernicus peaks. Supporting studies were performed dealing with the characteristics and interfaces of traverse geophysical instruments on the other scientific activities to be implemented on the J missions.

<u>Lunar Dust Erosion</u>

Bellcomm participated in the Working Group on the Scientific Aspects of Lunar Dust Erosion and in editing the final report to the Apollo Program Office. The study was concerned with the lunar dust erosion observed during terminal descent on Apollo 11 and 12. The Group concluded that: erosion started at about the same altitude on Apollo 11 and 12 but below that altitude visibility obscuration was worse on Apollo 12; there are no determinable differences in pertinent soil properties between the Apollo 11 and 12 sites; the lower sun elevation angle on Apollo 12 can qualitatively account for observed visibility differences; because of descent profile differences, erosion rates at the Apollo 12 site should have been somewhat greater than at Apollo 11. It was concluded that there is no reliable way to predict the erosion characteristics at future sites.

A separate analysis of the dust cloud generated by an exhaust plume suggested that the trajectory difference between Apollo 11 and Apollo 12 cannot alone explain the better visibility on Apollo 11.(43) Despite some uncertainties, turbulent effects were shown to be a plausible cause of the visibility difference. The higher sun angle on Apollo 11 was advantageous and could explain the visibility difference if the thickness of the dust layer generated in Apollo 11 was no more than twice that in Apollo 12.

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(42) <u>Lunar Atmospheric Mass Spectrometer Meeting at NASA Hq., March 6, 1970</u>, <u>Memorandum for File</u>, G. K. Chang, March 11, 1970.

(43) <u>Impairment of Terrain Visibility During LM Descent</u>, Memorandum for File, J. S. Dohnanyi, M. Liwshitz, T. T. J. Yeh, March 25, 1970.

Lunar Orbital Photography

An Apollo Orbital Science Photography Team was organized to advise NASA on Apollo photographic systems, photography planning, and data evaluation. Bellcomm representatives are on a number of associated working groups, including the Photographic Flight Plan Working Group, Crew Training Working Group, Panoramic Camera Working Group, Flight Film and Film Processing Working Group, and the Working Group on Earthshine and Near Terminator Photography.

The activities of the Photographic Flight Plan Working Group include photographic flight plan preparation and assistance in integrating photographic activities into the total flight plan. Specific photographic targets for Apollo 13 were selected and the corresponding photographic requirements were defined. Corresponding preparations for Apollo 14 were begun.

The Crew Training Working Group is responsible for training the astronauts in all matters related to photography. The Apollo 13 Prime and Backup Crews were briefed on the orbital science objectives including the visual observations from lunar orbit. The Apollo 14 Prime and Backup Crews were briefed on the orbital science mission objectives.

The Apollo 12 Lunar Exploration site photography was analyzed in terms of apparent resolution and terrain characteristics. The results were summarized in a presentation to the Apollo Orbital Science Photographic Team. One result of studying the Descartes site photography was the revision of the surface features previously mapped on the basis of Orbiter IV photography.

Bellcomm participated in the Headquarters Orbital Science Task Team. A presentation on Apollo Orbital Science with emphasis on the instrumentation was given to the Apollo Program Office.

Reduction of data from the Lunar Multispectral Photography Experiment (S-158) on Apollo 12 was begun. The initial results yielded the first positive identification of sharp, small-scale color differences on the lunar surface. A somewhat unexpected discovery was the lack of a color variation across the Fra Mauro Formation - Oceanus Procellarum boundary. Closer investigation shows that the area is covered by Copernican ray material. The implication is that Fra Mauro surface material is compositionally not very different from Copernican ray or Procellarum surface material. The results of the Apollo 12 Multispectral Photography Experiment are documented in a Technical Memorandum.(44) A report has also been written and transmitted to NASA for inclusion in the Apollo 12 Preliminary Science Report.

Master proofs were reviewed of the forthcoming publication, The Moon as Viewed by Lunar Orbiter, co-authored by F. El-Baz of Bellcomm and L. J. Kosofsky of NASA. The book will be available next quarter.

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(44) Apollo 12 Multispectral Photography Experiment, TM-70-2015-1, A. F. H. Goetz, February 20, 1970.

SKYLAB SYSTEMS ENGINEERING

Weight Reporting

Skylab I Weight and Performance reports for the months of January, February, and March were prepared, summarized for the Skylab Program Director and issued.

Skylab Program Specification

Specification Change Notices for a major update of the Program Specification were prepared and distributed for comment. These changes reflect the resolution of problems brought about by the change from the "wet" to "dry" Orbital Workshop and left open when the specification was originally issued.

Mission Sequence

Studies to determine the optimum duration of an astronaut "day" in orbit (24 hours vs. 23.5 hours) were updated and extended to investigate the effects of new baseline orbit parameters and the addition of the earth resources experiments to the vehicle payload.(45) Major conclusions of this study reaffirmed the compatibility of mission operations with either crew-day duration, but recommended that the 24-hour day be retained to avoid the disruption of flight plans that could result from failure of the crew to adapt to the shortened day.

Progress was made in developing a computer program that will aid in generating activity timelines for study of manned space missions.(46) Prototype schedules have been developed for the SL-2 mission. A standard data set has been compiled that contains preliminary descriptions of most Skylab crew activities. Graphic displays of timelines for crew activities, equipment use, and the expenditure of consumables can be provided.

Mission Design

Work was completed on a study of the impact on mission design of the variation of the sun line relative to the orbital plane.(47) Analytical expressions for determining β, the minimum angle between the solar vector and the

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(45) Astronaut Sleep Patterns During AAP Missions, Memorandum for File, D. J. Belz, February 26, 1970.

(46) Status Report on the Automated Task Scheduler (ATS) System, Memorandum for File, A. B. Baker, March 31, 1970.

(47) Solar Pointing Variations in Earth Orbit and the Impact on Mission Design, TR-70-620-1, B. D. Elrod, February 11, 1970.

orbital plane, and ψ, the location of orbital noon relative to the ascending node, were derived as a function of the orbit parameters. The relationship between a number of system performance factors and the solar vector orientation relative to the orbital plane were evaluated for circular orbits. Specific performance factors investigated were:

1) the bias gravity-gradient torque-impulse on a space vehicle in the solar-inertial mode,

2) the orbit sunlight interval,

3) the electrical energy per orbit available from solar arrays in various flight attitudes with incrementally articulated solar arrays and various space vehicle roll profiles, and

4) the incident thermal energy per orbit on a cylindrical vehicle in various flight attitudes.

All results were given in normalized form to facilitate application or approximation to particular vehicle configurations or orbit attitudes where appropriate.

A simplified mechanistic model of the sun-earth-orbital plane system was reported.(48) Use of the model facilitates visualization of the many significant parameters of earth-orbital space flight mechanics without use of coordinate transformations. In this model the earth orbital plane simultaneously revolves about the lateral surface and rotates about the vertex of an inertially oriented right circular cone. The cone also revolves about a fixed point with uniform circular velocity with its vertex in a plane. Equations are developed for the angles between the orbital and ecliptic planes and between the orbital plane and solar vector, β. General β angle envelopes for both date and time of launch are described. By consideration of appropriate angles in the cone base, the times from orbital insertion to angular extrema between the orbital plane and solar vector are determined.

A study of the characteristics of coelliptic orbits of the form planned for use in the Skylab rendezvous showed that these orbits vary only a few hundred feet from true coellipticity, even when the effects of the asphericity of the earth is considered.(49)

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(48) A Mechanistic Visualization of the Sun-Earth-Earth Orbital Plane System, TM-70-1022-10, J. W. Powers, March 31, 1970.

(49) Some Characteristics of Coelliptic Orbits, Memorandum for File, P. H. Whipple, February 17, 1970.

A study was completed of the phasing capability of the Coelliptic Sequence Initiation/Constant Delta Height (CSI/CDH) sequence of maneuvers that could be used for the intermediate portion of the Skylab rendezvous.(50) The basic conclusions of this study are applicable to the Corrective Combination maneuver that has been substituted for the CSI maneuver in current Skylab mission planning.

A study of the effect of varying the targeted time of the CDH maneuver in order to gain additional control of the time of the TPI (Terminal Phase Initiation) maneuver for a typical Skylab trajectory showed that the TPI time could be varied over a range of about 1200 seconds if CDH is performed before apogee of the pre-CDH orbit. The technique would, however, require a significant increase in the rendezvous delta-v budget.(51)

Earth Resources Studies

The capability of the Skylab systems to support the requirements of a set of proposed earth resources experiments was studied. The results of a preliminary compatibility analysis were discussed with the Center Program Offices and the Program Director.(52) The investigation covered a) Launch Opportunities and Instantaneous Impact Points, b) Lighting Constraints and Ground Truth Sites, c) Attitude Control, d) Electrical Power, and e) Thermal Characteristics, with the following results:

a) Launch Opportunities and Instantaneous Impact Points - An evaluation of the increase of the Skylab orbital inclination from 35 to 50 degrees showed the effects on the SL-2 launch window, growth margin, and the number of launch windows.(53) For a 700-pound fuel allocation for yaw steering the SL-2 launch window is reduced from 28 minutes to 16 minutes, and the payload margin is reduced from 2980 pounds to 1939 pounds. SL-2 can be launched on only four consecutive days after the launch of SL-1, instead of five.

Graphs were generated which depict the opportunities for launching SL-2 as a function of the time from SL-1 launch for the rendezvous profile recently proposed by MSC.(54) The graphs show that the launch opportunities are cyclic in nature and that no launch opportunity exists on the fifth day if the constraint that the total time of rendezvous shall be less than 24 hours is observed.

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(50) A Study of the Phasing Capability of Apollo CSI/CDH Rendezvous Targeting Routines for AAP, Memorandum for File, C. O. Guffee, R. C. Purkey, February 19, 1970.

(51) Effect of Varying Time of CDH Upon Time of TPI for Coelliptic Rendezvous, Memorandum for File, C. O. Guffee, R. C. Purkey, March 31, 1970.

(52) System Compatibility Analysis Earth Resources Experiments Proposal, Memorandum for File, G. M. Anderson, et al, February 11, 1970.

(53) Comparison of AAP-2 Launch Windows and Launch Opportunities with the SWS at 35 and 50 Degree Inclinations, Memorandum for File, W. L. Austin, February 10, 1970.

(54) Skylab-2 Launch Opportunities and Time in Coelliptic Orbit, Memorandum for File, W. L. Austin, March 31, 1970.

A comparison of the amount of time the instantaneous impact point (IIP) of the Skylab-1 launch vehicle spends over Europe as a function of orbital inclination showed that for an inclination of 47 degrees, the IIP dwell time is about 1.8 seconds compared to 5.3 seconds for an inclination of 50 degrees.(55)

b) Lighting Constraints and Ground Truth Sites - A new Skylab mission planning tool was developed which enables one to view simultaneously the effect of launch date and time on launch lighting, recovery lighting, mission beta angle history, and the lighting available for earth resources photography.(56)

An evaluation was made of a proposal to limit the earth resources mode to those periods of a mission when the angle between the sun and the orbit plane (β) is less than 30° absolute.(57) The intent of this proposal was to minimize thermal and electrical problems. It was found that if $|\beta| \leq 30°$, the number of photographic opportunities is reduced by 30% for targets on the equator and by 41% for targets at 50° latitude. If $|\beta| \leq 45°$ is acceptable, the reduction is 10 to 13% and for $|\beta| \leq 60°$ there is no reduction.

Opportunities to photograph ground targets from the Skylab orbit were analyzed for Experiment S190, the Multispectral Photographic Facility.(58) Operation in both the solar-inertial attitude with the camera mounted flexibly, and in the local vertical attitude with the cameras mounted rigidly was studied. Photographic opportunities were strongly dependent on latitude, recurred on a 60-day period due to regression of the orbit plane, and were numerous in the summer and sparse in the winter.

A specific set of ground sites to be photographed as part of the Skylab earth resources experiments has not yet been selected. However, the Earth Resources Experiment Package documentation contains numerous references to comparison of data collected from the spacecraft with data collected by ground and aerial surveys. From the set currently scheduled for aerial survey, it is possible to pick for study those sites most likely to be selected. A study of the latitude distribution of the sites selected for the NASA FY70 aircraft mission schedule was performed.(59) The study showed that there is a relative sparsity of sites at latitudes near 50°. A 44° inclination orbit would cover all the oceanography

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(55) Comparison of Skylab IIP's for Inclinations of 45, 47 and 50 Degrees, Memorandum for File, W. L. Austin, March 31, 1970.

(56) Preliminary Skylab Mission Planning: Graphical Determination of Lighting Considerations, Memorandum for File, E. W. Radany, March 31, 1970.

(57) Effects of Target Lighting and β Constraints on Skylab Ground Site Photography, TM-70-1022-8, B. D. Elrod, March 30, 1970.

(58) Photography of Ground Sites from AAP Orbit, Memorandum for File, D. A. De Graaf, E. W. Radany, February 12, 1970.

(59) Tentative Skylab Earth Resources Ground Truth Site Distributions, Memorandum for File, E. W. Radany, March 30, 1970.

(except Barrow, Alaska) and geography sites. A 46° inclination orbit would cover all the geology sites and a 48° inclination orbit covers all the hydrology sites and all except one agriculture/forestry site.

c) Attitude Control - The planned installation of the earth resources sensors in SL-1, with relatively little or no individual experiment pointing freedom, requires a local vertical attitude during experiment operational periods to access targets on the earth. Three different methods of acquisition and control of the local vertical attitude were investigated.(60) The preferred method uses the control moment gyro (CMG) system in a mode that initiates and terminates the local vertical attitude at orbital midnight. Reaction thrust propellant required for CMG momentum management is less than 20% of that required by control modes based entirely on reaction thrust.

The implementation of the CMG method of attitude control has an important side benefit. The reduced reaction thrust propellant requirement can readily be accommodated by the Skylab Thruster Attitude Control System. CSM provisions for this function are not required, thereby avoiding a complex interface.

A backup technique was formulated for determining Skylab orientation about the sun line.(61) The Skylab geometric Z axis in its nominal attitude is directed towards the sun. Knowledge of the orientation about this axis is required to acquire any accurate local vertical attitude for earth resources experiments. A single star tracker provides the attitude reference for determining this orientation. As a backup in the event of star tracker failure, a method was formulated that uses measurements of CMG angular momentum components to determine the Skylab rotation angle about the Z axis.

d) Electrical Power - In the earth resources mission mode, solar array power output is substantially less than power generated in the usual solar inertial attitude when the arrays are continuously pointed at the sun. A detailed study of the Skylab power system capabilities in this attitude mode was performed.(62) Unlike the solar inertial mode, the angle of incidence of the rays of the sun is other than zero, and this results in a cosine loss in incident energy plus an increase in the energy reflected from the solar cell coverslides. The earth resources attitude is such that a larger average percentage of the arrays

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(60) A Study of Some Attitude and Control Options Compatible with the Performance of Earth-Pointing Experiments by the AAP Cluster, TM-70-1022-2, J. J. Fearnsides, February 3, 1970.

(61) Backup Technique for Determining AAP Cluster Orientation about Sun Line, TM-70-1022-4, R. A. Wenglarz, March 19, 1970.

(62) AAP Electrical Power System Capabilities in the Earth Resources Mission Mode, TM-70-1022-6, W. W. Hough, B. W. Moss, J. J. Sakolosky, March 23, 1970.

powering the Airlock system will be shadowed by the ATM arrays.[63] On the positive side, the average temperature of the arrays will be lower than in the solar inertial mode, giving rise to slightly better array performance.[64]

The basic assumptions made for this analysis were that the experiment viewing axis is directly opposite the solar array outward normal, and that this axis is aligned with the local vertical at an orbital midnight and remains aligned until a subsequent midnight. In order to perform earth resources experimentation for one to several consecutive orbits, the system power requirements must be reduced and/or an operational ground rule that the state-of-charge of each battery must return to 100% during the illuminated portion of each orbit must be set aside. It appears that an acceptable combination of decreased power requirements and permissible battery depth-of-discharge can be chosen such that two, and perhaps three consecutive orbits are possible without imposing any severe restrictions on the sun-line/orbit-plane angle, β.

e) Thermal Characteristics - Battery cells require relatively tight temperature control to insure adequate cell life. The passively controlled ATM Charger/Battery/Regulator Modules (CBRMs) are shadowed in the solar inertial attitude. In the earth pointing X-IOP/Z-LV attitude some CBRMs are exposed to direct solar heating, and the critical battery cells heat up. Five solar inertial to X-IOP/Z-LV missions were analyzed to determine transient cell temperatures.[65] It was found that, with a fully degraded thermal control coating and a 200 watt operating level, at least one pass can be completed with CBRMs exposed to direct solar heating without exceeding the temperature limits of the cell. With a partially degraded thermal coating at a lower operating level, two or more consecutive passes in the earth pointing attitude can be completed.

Communications Studies

A study of the communications and tracking coverage provided by the Manned Space Flight Network (MSFN) for Skylab missions at different orbital plane inclination angles showed that the number of coverage gaps that are longer that 90 minutes increases sharply as the orbital inclination is increased from 45 to 50 degrees.[66] This coverage parameter is of particular interest because the record capacity of a single Apollo Telescope Mount tape recorder is 90

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(63) Shading of the AAP Workshop Solar Array by the ATM Array, TM-70-1022-9, J. J. Sakolosky, March 31, 1970.

(64) Solar Array Temperatures During the AAP-SWS Earth Pointing Experiments Mission Mode, Memorandum for File, J. W. Powers, January 28, 1970.

(65) Thermal Response of the ATM Charger/Battery/Regulator Modules During the Proposed SL Earth Oriented Missions, Memorandum for File, J. E. Waldo, D. P. Woodard, G. M. Yanizeski, March 27, 1970.

(66) An Extension of the Study of MSFN Configurations for Coverage of Skylab Missions, Memorandum for File, J. P. Maloy, March 23, 1970.

minutes. The study also showed that the contact time between the Skylab and the MSFN decreases by approximately 12.5% when the inclination of the orbital plane is increased from 35 to 50 degrees.

Telemetry Data Compression

An assessment was made of the feasibility of using an onboard IBM 4 Pi/EP computer to compress and merge the two 51.2 Kbs and the 72 Kbs Skylab telemetry streams.[67] It was estimated that the total of 174.4 Kbs could be reduced to about 20 to 35 Kbs, but that the speed and memory capacity of the proposed computer are not adequate to handle this load. With the computer operating close to maximum speed, it has the capability to compress and merge the two 51.2 Kbs streams.

Potable Water System

A review was conducted of the Apollo experience with potable water supply systems and the effect of this experience on the design of the Skylab water management system.[68] The Skylab design utilizes stainless steel tanks and plumbing in an effort to avoid materials compatibility problems. The system is designed so that there are no paths for bacteria migration between tanks. In addition, thorough sterilization techniques will be employed to prevent preflight contamination of the system.

Orbital Workshop Film Vault

A conceptual design for the Orbital Workshop film storage vault was evaluated to determine adequacy of the vault to provide radiation protection for the film. This design consists of one large film vault with aluminum shielding material that is to be installed by the crew after the SL-2 spacecraft docks to SL-1. It was concluded that the design is adequate for a nominal mission or for the case of SL-2 launch delays on the order of 14 to 30 days. Additional shielding of the SL-1 launch configuration would be required to protect the film if manning of the Workshop was delayed more than 30 days.

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(67) Onboard Computing Capability Required to Compress AAP Telemetry Data, Memorandum for File, D. O. Baechler, R. J. Pauly, January 7, 1970.

(68) Effects of Apollo Program Experience on the Design of the AAP Cluster Water Management System, Memorandum for File, J. J. Sakolosky, February 4, 1970.

Thermal System Studies

A study was made of the relative effectiveness of water versus water glycol for cooling of the ATM control and display panel. (69) Water was found to be the more effective coolant and requires less pump power and pressure.

Stellar Astronomy

A major question concerning the development of large astronomical systems with stringent pointing requirements concerns the possible deleterious effects of crew motion. As a part of Skylab II studies, an analysis was completed of the structural distortion and resulting optical degradation of a Cassegrain telescope due to crew motion in a large spacecraft. (70) Three specific designs, a one-meter f-30, a one-meter f-60, and a two-meter f-60, were investigated using a model that included the basic structure, mirrors, detailed mirror mountings, and an experiment package. All three designs were found to retain their diffraction-limited performance when excited by deterministic representations of crew motion disturbances or by worst case control system disturbances.

The investigation of telescope structure response to random crew motion involves the solution of the matrix Riccati and related equations. A survey of methods of solving these equations was prepared. (71)

Review of Space Station Technology Program Plan

The Space Station Technology Program Plan was reviewed. (72) This review served two objectives:

1) to identify the support Skylab is currently planning for the Space Station/ Space Base, and

2) to identify potential support which Skylab might provide for the program.

The report covers the various disciplinary areas included in the Plan. The planned and potential Skylab support for space station and base technology are identified.

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(69) Behavior of Water vs Water Glycol for Control and Display Panel (Dry OWS), Memorandum for File, D. G. Miller, January 15, 1970.

(70) Support Motion Induced Vibrations of an Orbiting Cassegrain Telescope, TM-70-1022-3, P. G. Smith, March 17, 1970.

(71) Survey of Numerical Solutions of the Matrix Riccati Equation, Memorandum for File, P. G. Smith, January 23, 1970.

(72) Review of Space Station Technology Program Plan, Memorandum for File, G. M. Anderson, et al, February 4, 1970.

The performance of the air/ground voice communications with the spacecraft during the Apollo 12 mission launch was analyzed to determine the effects of (1) the lightning strikes shortly after liftoff and (2) the removal of the Grand Bahama station from the MSFN.(73) The analysis showed that the lightning resulted in a loss of unified S-band (USB) communications for about 30 seconds, but VHF communications were only slightly affected. USB communications were lost for about a minute at separation of the SIC stage, which occurred during the time that the Grand Bahama station would have provided coverage. VHF coverage from the MSFN station (MIL) at KSC was continuous during this interval. An FM voice receiver at MIL for the USB downlink was suggested to reduce the duration of USB loss.

A survey of coding techniques applicable to space communications systems showed that these techniques are potentially useful at Earth orbital, lunar, and deep space distances.(74) They are particularly attractive when very low error rate performance is required. Unmanned programs have demonstrated gains of approximately 5 dB which implies an increase in transmission rate by a factor of three or more or the corresponding reduction in transmitter power or antenna size.

Phase lock loops are widely used in the Apollo communications systems. Continuing studies of their performance have led to a model that characterizes static phase error and the time to slip a cycle for a large class of nth order phase lock loops.(75) The procedure developed in this study can also be used to characterize the behavior of several other nonlinear devices, for example, the delay lock loop.

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(73) Analysis of Air-Ground Voice Contacts During the Apollo 12 Launch Phase, Memorandum for File, L. A. Ferrara, March 16, 1970.

(74) Error-Correcting Coding Techniques For Space Communication Systems, TM-70-2034-1, B. P. Tunstall, January 21, 1970.

(75) Characterizing the Behavior of Phase Lock Loops, TM-70-2034-2, L. Schuchman, February 20, 1970.

SPECIAL TASK ENGINEERING STUDIES

Analysis of Haze Effects on Martian Surface Imagery

Task Order No. 35

In support of the Mariner Mars '71 mission planning effort, analyses were carried out to define an exploratory mode for photography from the orbital spacecraft assigned to the study of time variable features of the atmosphere and surface.(76) The purpose of the exploratory mode is to scan the full 360° of longitude early in the mission to provide a data base for decisions on which longitudinal regions to study in detail later in the mission.

Analyses have shown that during the first few days of the mission, exploratory mode photography could be acquired by entering the nominal mission orbit and taking a different set of pictures. The only orbital parameters which might be adjusted after studying the exploratory pictures would be the longitude of periapsis, and this could be accommodated with a small ΔV maneuver.

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(76) Mariner Mars '71 B Mission - A Candidate Exploratory Phase Mission Plan, Memorandum for File, G. A. Briggs, March 30, 1970.

GENERAL MISSION ENGINEERING STUDIES

Manned Space Flight Program Planning

Space Shuttle - Several potential payloads for future manned space flight missions, such as the Space Station and the Nuclear Shuttle, exceed the surface-to-orbit delivery capability of the fully reusable Space Shuttle in its present concept. Two studies were conducted to investigate the feasibility of using the Space Shuttle booster stage in conjunction with a vehicle which would replace the orbiter stage and permit delivery of larger payloads, possibly eliminating the need to maintain the Saturn V.

In one of the studies, it was shown that if the reusable second stage of the Space Shuttle were replaced by an expendable S-IVB, payloads weighing between 75,000 and 100,000 pounds could be delivered to low earth orbit, as compared with 25,000 and 50,000 pounds for the fully reusable concept.(77) The booster trajectory becomes critical in this concept, as launching the S-IVB drives the booster stage toward excessive velocity and a steeper reentry angle. This steep trajectory must be controlled to permit the booster to return safely to earth. It was also found that with appropriate modifications, the S-IVB could serve as a reusable in-space stage for missions up to 30 days duration. Operating much beyond 30 days without refueling requires a refrigeration system to prevent excessive hydrogen loss. However, weight and power estimates suggest this is impractical. Two S-IVBs in tandem would provide an in-orbit payload capability equivalent to that of the Nuclear Shuttle.

The results of a second study indicate that the Nuclear Shuttle can place itself in earth orbit with the help of the reusable booster stage of a 25,000 pounds payload Space Shuttle.(78) To do this, the nuclear stage must be only partially loaded with propellant and its engine must be started before it attains orbital velocity. Because of the low thrust of the nuclear engine, a complex trajectory (similar to that of the above case of the S-IVB second stage) is necessary to prevent excessive aerodynamic loads on the booster during its reentry.

The feasibility of launching a Space Shuttle second stage (Orbiter) with a Saturn V S-IC booster stage from Launch Complex 39 was examined.(79) The concept appears feasible provided the length and configuration of the Orbiter are compatible with the launch unbilical tower (LUT). It appears that a maximum

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(77) The SIVB as a Space Shuttle Second Stage and Reusable In-Space Stage, TM-70-1013-4, D. Macchia, J. Schelke, et al, March 10, 1970.

(78) Orbital Insertion of the Nuclear Shuttle Using a Sub-orbital Start and a Space Shuttle Booster, Memorandum for File, D. J. Osias, March 5, 1970.

(79) Feasibility of Shuttle (Orbiter)/S-IC Launches at LC-39, Memorandum for File, C. H. Eley, III, December 31, 1969.

launch rate as high as 20 per year could be achieved if two LUTs were used and if the LUT refurbishment time was not greater than two weeks following each launch.

Space Shuttle Payloads - A study was initiated to investigate the potential impact of the Space Shuttle on unmanned satellite missions. The reference Shuttle was assumed to be capable of up and down delivery of either 50,000 or 25,000 pounds of payload to a 270 nm, 55° inclination orbit. Using this Shuttle, the capability to deliver, revisit, and recover the satellites contained in the NASA long-range plan for the decade of the 70's is being examined. Preliminary calculations indicate that the Shuttle has the capability to deliver each of the satellites to its specified orbit on a single Shuttle trip, and frequently more than one satellite can be delivered on the same trip. Most of the low altitude earth orbital satellites can be delivered directly; delivery of all satellites including planetary can be accommodated by providing an upper stage no larger than Centaur.

In addition, the Shuttle offers potential advantages for satellite reuse through its capability for revisit and recovery. Facility class satellites such as OAO and HEAO are under study to explore the impact of reuse on the design and operation of these satellites. The possibility of using the Shuttle itself as an experiment platform is also under examination.

Space Tug - A survey was made of potential future transportation requirements for the Space Tug. Transportation modes considered were the movement of men and materials between different orbits around the earth and between orbit and the surface of the moon, as well as out-of-orbit injection for unmanned planetary payloads.[80] Representative Tug sizes were reviewed with emphasis on earth orbit applications and alternative lunar mission modes. A Tug of about 50,000 pounds gross weight appears to satisfy currently identified missions in all areas of the program. A small Tug weighing about 10,000 pounds can only provide limited earth orbit maneuvering capabilities.

Manned Space Flight Experiment Program Studies

Space Physics - Design and performance parameters have been derived for a superconducting magnet for a high energy cosmic ray facility in space.[81] A torus-shaped wire wound magnet with an outside diameter of about 0.5 meters, weighing 60 kilograms and operated at a temperature of 12° K could provide a magnetic field of about 16 kilogauss. Space performance of such a system would be limited by the ability to keep the magnet cooled.

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(80) Space Tug Operations in Association With the Integrated Program, Memorandum for File, M. H. Skeer, January 9, 1970.

(81) Superconducting Magnet Parameters of the Superconducting Levitron Coils, Memorandum for File, L. Kaufman, February 3, 1970.

Astronomy - The scientific objectives, present status of instrumentation technology, and plans for future space research in stellar X-ray and gamma-ray astronomy were reviewed.(82) The need for automated sky surveys to precede X-ray and gamma-ray experiments on manned spacecraft was stressed.

Optical Contamination - The need for instruments to study optical contamination in the vicinity of Skylab spacecraft was examined.(83) It was observed that on Skylab I, in addition to those experiments designed specifically for contamination studies, ATM will provide relevant information. Several observations and recommendations were made: 1) data relevant to the manned spacecraft optical environment could be obtained from experiments during Apollo missions; 2) an optical environment handbook should be prepared for future experimenters; and 3) for missions following Skylab I, the optical contamination environment should be monitored by small, inexpensive sensors to support real-time planning of the more sophisticated astronomy experiments.

Scientific Studies

Trajectory Analyses - A computer program was completed which provides the capability for determining planetary ballistic flyby opportunities for a given pair of Earth launch - Earth arrival dates.(84) Once the solution for the initial pair of launch and arrival dates has been determined by conventional patched conic techniques, the solutions for other pairs of dates, within 5-10 days of the initial set, can be arrived at more efficiently. The planetary encounter types can include stopover and impulsive flybys in addition to the ballistic flybys.

Efforts to improve the accuracy of trajectory calculations for a spacecraft approaching a planet under the gravitational influence of the sun have led to an advancement in the theory of second order linear differential equations.(85) It was shown that equations whose solutions consist of a finite number of elementary functions can be classified in a manner similar to a table of integrals, so that variant forms of such equations can be recognized and solved exactly. As a result, it may be possible to obtain analytic solutions to a linearized form of the restricted three-body problem that results from neglect of the mass of the spacecraft in comparison with the solar and planetary masses.

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(82) Scientific Motivations for Stellar X-ray and Gamma Ray Astronomy - Review and Directions for Manned Space Flight Participation, TM-70-1011-2, F. F. Tomblin, January 30, 1970.

(83) Optical Contamination in Space: A Program for Decision, Memorandum for File, A. C. Buffalano, March 5, 1970.

(84) INTAP - Interplanetary Trajectory Analysis Program, TM-70-1032-2, R. W. Grutzner, January 26, 1970.

(85) Differential Equations Soluble in Finite Terms of Elementary Functions, TM-70-1014-1, C. C. H. Tang, March 26, 1970.

Navigation and Guidance Requirements - The requirements for navigational data to support a range of manned and unmanned planetary missions, including the Grand Tours, have been reviewed.(86) It was found that data from unmanned flyby and orbiter missions will be much more effective than earth-based measurements in fulfilling the increasingly stringent requirements imposed by some of the advanced missions. Both flyby and orbiter missions will improve measurements of the planetary mass and the astronomical unit. Orbiter missions will also improve measurements of the planetary gravitational field, ephemerides, geometrical figure, and atmospheric profiles. It was concluded that, for most unmanned planetary missions, spacecraft-based approach navigation systems are desirable but not mandatory. For manned planetary missions and certain unmanned swingby missions, such autonomous systems appear to be mandatory for mission reliability.

Atmospheric Temperature Profiles - An analytic system for obtaining vertical temperature profiles of the atmosphere using a satellite-borne carbon dioxide laser was developed.(87) Experimentally this system requires laser operation at several frequencies over a 2 gHz range. Since tuning a laser over such a large frequency range is difficult, an alternate method was proposed in which the laser could operate at several discrete frequencies by using a gas mixture containing different isotopic varieties of CO_2.

Project Tektite - A paper discussing the collection and management of data on crew behavior during the Tektite I underwater program was delivered at the annual meeting of the American Association for the Advancement of Science.(88) The observation methodology and procedures employed in collecting behavioral data were described, as well as the computer-based data management system developed to organize the data for subsequent scientific analyses by individual investigators.

Mathematical Techniques - Deriving specifications for optimum and suboptimum linear phase locked loop FM receivers to demodulate frequency modulated signals (such as used in the Apollo S-band system) often involves making rational approximations of telemetry signal spectra. In characterizing the behavior of the FM receivers as functions of time it is necessary to obtain the inverse Fourier transforms of these rational approximations. It was shown that the inverse Fourier transform of any rational algebraic function can be

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(86) Navigation and Guidance Aspects of Data Acquisition Requirements for Planetary Missions, Memorandum for File, C. C. H. Tang, March 25, 1970.

(87) Atmospheric Temperature Profiles Using Satellite-Borne Laser, TM-70-1011-1, W. A. Gale, January 13, 1970.

(88) Authored Paper Delivered at 136th Annual Meeting of the American Association for the Advancement of Science, Memorandum for File, R. S. Mach, February 6, 1970.

obtained directly from either its inverse Laplace transform or a derived table.[89] A computer program was subsequently developed to carry out this operation.

Technological Studies

Space Shuttle - The advanced rocket engine design concepts for the main propulsion system of the Space Shuttle were evaluated in the light of planned Shuttle operations for the late 1970's.[90] One concept, the Staged Combustion High Pressure Bell, is characterized by a combustion pressure about three times that of present liquid propellant rockets and a conventional bell-shaped nozzle. A new engine cycle in which the propellant is burned in two stages is necessary to achieve the high combustion pressure. The other concept, called the Aerospike, uses a conventional operating cycle with moderate combustion pressure, but with an advanced, unconventional nozzle. The study concluded that although both concepts are technically feasible, the Staged Combustion High Pressure Bell engine technology is better understood, and the engine design is less closely coupled to the vehicle configuration.

Significant factors affecting the selection and design of a reusable radiative thermal protection system for the Space Shuttle were identified.[91] These factors include configuration concepts, materials availability and selection, and a number of other design problems such as vibration and protection of special regions. It was suggested that a thermal protection system that could interchangeably use ablative or radiative heat shield materials is an attractive concept. The ablative material could serve as an evolutionary step or as a backup to the operationally desirable but technically difficult radiative heat shield.

The technology status of candidate materials for a radiative heat shield was examined.[92] It was found that uncertainties exist with regard to performance reliability and reusability for all of these materials. Coated columbium appears to be the most promising for heat shields subjected to temperatures up to 2500°F. Thoria dispersion strengthened nickel chromium is promising for long life applications without coatings for temperatures up to 2200°F.

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(89) Explicit Inverse Fourier Transformation of a Rational Function and a New Theorem, TM-70-1033-2, S. Y. Lee, February 2, 1970.

(90) Space Shuttle Propulsion Issue, Staged Combustion Bell Versus Tap-Off or Gas Generator Aerospike (U), TM-70-1013-1, C. Bendersky, February 3, 1970, CONFIDENTIAL.

(91) Radiative Thermal Protection System Considerations for the Space Shuttle, Memorandum for File, C. C. Ong, January 16, 1970.

(92) Radiative Thermal Protection System Materials for Reusable Reentry Vehicles, TM-70-1013-3, C. C. Ong, March 6, 1970.

Meteoroid Shielding - Design problems encountered with meteoroid protection systems were investigated in an attempt to identify meteoroid shielding requirements for in-space stages and, in particular, for an earth-orbit to lunar-orbit shuttle.(93) The meteoroid environment will be an important design consideration for advanced space hardware because of anticipated large surface areas and long operating lifetimes. Substantial uncertainties in the parameters governing the design of meteoroid shielding stem from limited knowledge of the meteoroid environment and incomplete understanding of penetration mechanics. Although no solution to this basic problem appears imminent, it would be desirable to adopt for preliminary design studies a standard set of criteria such as the Natural Environment and Physical Standards document used in the Apollo and Skylab Programs. This would reduce the wide range of meteoroid shielding weight estimates that currently prevail, thus affording a more meaningful comparison between design alternatives.

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(93) The Effect of Meteoroid Shielding on In-Space Stage Performance, TM-70-1013-2, C. E. Johnson, M. H. Skeer, March 10, 1970.

ENGINEERING SUPPORT

Computing Facility

The UNIVAC 1108 computer operations were continued under the EXEC 8 multi-processing system. During the quarter modest adjustments were made in the computer configuration. Two FH 432 drums were replaced by one FH 1782 drum resulting in more efficient use of mass storage.

During the period from January 1 to March 31, NASA Headquarters usage of the UNIVAC 1108 computer was 26,800 charge units.

Applications Programming

A computer program was completed which provides a systematic approach to parametric analysis of systems whose characteristics (dependent variables) are continuous functions of the system parameters (independent variables).[94] Program design features, extensive use of interpolation and extrapolation, and a flexible contour plotting capability are used to minimize the number of system evaluations required to provide a given degree of parameter space coverage.

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(94) PAP - Parametric Analysis Program, TM-70-1032-1, P. F. Long, January 21, 1970.

LIST OF REPORTS AND MEMORANDA

(List in Order of Report Date)

This index includes technical reports and memoranda reported during this period covering particular technical studies.

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TITLE	DATE
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Effect of Varying Time of CDH Time of TPI for Coelliptic Rendezvous, Memorandum for File, C. O. Guffee, R. C. Purkey	March 31, 1970
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TITLE	DATE
Impact of J Mission Payload Requirements on L/V Structures and Control Dynamics, Memorandum for File, R. E. Hunter	March 31, 1970
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